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Analysing Coarticulation in Scottish English Children and Adults: an Ultrasound Study

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1. INTRODUCTION

One of the gaps in our knowledge about developmental paths taken by children to adult-like motor control of speech concerns the development of coarticulation. There have been a number of studies which compared coarticulatory patterns in children and adults, but these studies have produced conflicting results: some show that children exhibit less coarticulation than adults (e.g., [2]); a similar amount (e.g., [6]); or more (e.g., [4]; [3]). A greater within-speaker variability in articulatory patterns exhibited by children than by adults may have contributed to the equivocal results. Another factor may be that most previous studies relied heavily on acoustic analysis, which provides only indirect evidence of articulatory movements, and is particularly problematic in child speech, because of the high fundamental frequency and consequent difficulties with formant tracking. Possibly as a result of the relative unavailability of suitable articulatory instrumental techniques, developmental studies of coarticulation comparing adults' and children's productions using articulatory data are very few (e.g., an EMA study reported in [1]). An advantage of ultrasound over EMA is that it is non-invasive, and it registers the movement of the whole midsagittal section of the tongue, including the tongue root.

This study used articulatory measures derived from ultrasound imaging for comparison of coarticulation in children and adults. The research questions were:

1) Do children demonstrate a significant difference from adults in coarticulatory patterns, and if there is a significant difference, what is the direction of the difference?

2) Do children exhibit significantly greater within-speaker variability than adults in their patterns of coarticulation?

2. METHOD

The data were the syllables /ʃi/, /ʃu/ and /ʃa/, in the carrier phrase "It's a ... Pam" (ten repetitions). The participants, all native speakers of Standard Scottish English, were three normally developing children aged 6 to 8 years (C1 male aged 8;4, C2 female aged 6;10, C3 male aged 6;4), and three adults. Synchronised ultrasound and acoustic data were collected using the Queen Margaret University ultrasound system ([7]).

A new methodology for analysing ultrasound data (see [8]) was used. Ultrasound frames at two time points, the middle of the consonant and the middle of the vowel, were identified in each of the different CV sequences, based on the acoustic data. At each time point, a cubic spline was automatically (with subsequent manual correction) fitted to the tongue surface contour. Each spline was defined in terms of xy coordinates, and these coordinates were used for comparing tongue curves.

Tongue curve comparison was based on nearest neighbour calculations (e.g., [5]). Magnitude of Coarticulation (MC) for the consonant in each of the three pairs of vowel environments was calculated, separately for each subject. The following formula for calculating MC was developed:

$$MC_C = \frac{V1 - V2}{(C_{V1} - V1) + (C_{V2} - V2)}$$

In the formula, C is the target consonant; V1 and V2 are two vowel phonemes providing the alternative conditioning environments; C_{V1} is C in the environment of V1; C_{V2} is C in the environment of V2. This measure of coarticulation expresses the ratio of the difference between the vowel contours (which is proportionate to the possible degree of consonantal adaptation offered by the two vowel contexts) and the sum of the consonant-vowel differences in each vowel environment (which is in inverse proportion to the degree of consonantal adaptation to the vowel contexts). The greater the MC value, the stronger is the coarticulatory effect produced on a given consonant by the two vowels.

For each speaker, for the consonant in each pair of vowel contexts, MC values and Coefficients of Variation across ten tokens were obtained. MC values and Coefficients of Variation were compared across age group and vowel pair.

3. RESULTS

Table 1 presents MC values and Coefficients of Variation for each subject. The Univariate ANOVA showed a significant main effect of age group on MC ($F = 369.49$; $df = 1$; $p < 0.001$). On average, MC was greater in children (mean MC of 1.00 in children versus mean MC of 0.80 in adults). Note also a difference in MC across vowel pairs (F = 1372.45; df = 2; p < 0.001), with the pair /i/-/u/ affecting the consonant the least, and the pair /a/-/i/ producing, on average, the greatest effect.

Table 1. MC values and Coefficients of Variation (CV) in three children (first three rows) and three adults (last three rows). Standard Deviations for MC are in brackets.

	MC, a/i	MC, a/u	MC, i/u	CV
C1	1.40 (*0.21*)	1.36 (*0.26*)	0.39 (*0.15*)	23.9
C2	1.30 (*0.27*)	0.81 (*0.27*)	0.93 (*0.14*)	23.5
C3	1.05 (*0.10*)	1.11 (*0.11*)	0.69 (*0.24*)	13.1
S1	0.97 (*0.07*)	0.91 (*0.09*)	0.50 (*0.07*)	10.5
S2	1.02 (*0.07*)	1.18 (*0.11*)	0.24 (*0.05*)	12.8
S3	1.09 (*0.06*)	0.94 (*0.11*)	0.38 (*0.05*)	8.8

Figure 1 presents tongue curves for /ʃi/ and /ʃa/ in a child participant C2 and in an adult participant S1. The figure shows relatively small distances between the consonant and the vowel in C2, compared to S1; this difference has contributed to the greater MC in this child than in this adult.

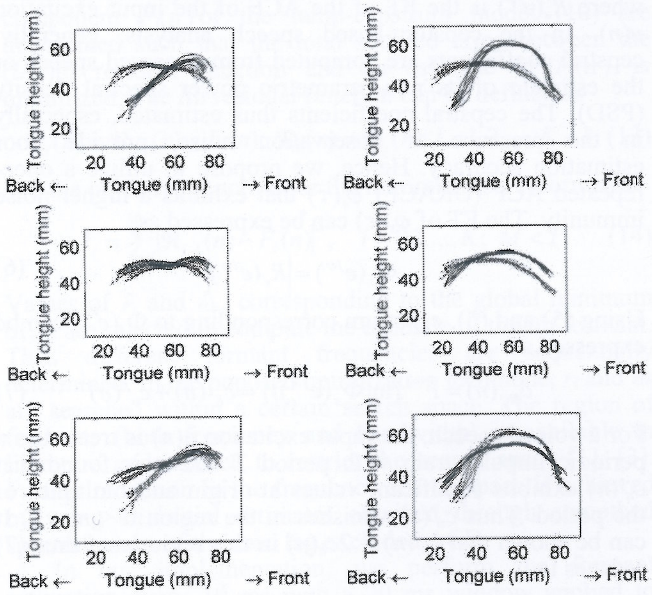

Fig. 1. Tongue contours for /ʃa/ and /ʃi/ in C2 (left) and S1 (right). Row 1: /i/ from /ʃi/ (solid) and /a/ from /ʃa/ (dashed). Row 2: /ʃ/ (solid) and /a/ (dashed) from /ʃa/. Row 3: /ʃ/ (solid) and /i/ (dashed) from /ʃi/. Lines for 10 repetitions are presented.

An independent t-test demonstrated a significant difference in the Coefficient of Variation between adults and children (t = 2.64; df = 16; p < 0.05). Table 1 illustrates greater values of the Coefficient of variation in children.

4. DISCUSSION

In this study, children showed a significantly greater amount of anticipatory lingual coarticulation than adults. This finding is in agreement with [3] and [4], but it contradicts [2] and [6]. Coefficients of variation were significantly greater in children than in adults. This shows that adults and children differ in the degree of within-speaker variability in coarticulatory patterns, children being more variable than adults. These results agree with existing literature (e.g., [3]). We are planning to conduct an acoustic analysis of these data, to find out whether acoustic results will corroborate our articulatory findings. A qualitative examination of patterns for each speaker will also be conducted, to establish whether individual results contribute disproportionately to a group picture.

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